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RESEARCH TRENDS IN THE AREA OF
COMBUSTION AT THE AVIATION
INSTITUTE

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Foreign Technology Division
Wright-Patterson Air Force Base, Ohio

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RESEARCH TRENDS IN THE AREA OF COMBUSTION AT THE AVIATION INSTITUTE

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At the Aviation Institute studies in the area of combustion are carried out by the Department of Combustion, which was established on the basis of the Department of Airless-Injection Engines, which evolved from the Combustion Section. Works dealing with the processes of combustion began in 1946-1947 as studies on ramjet and pulsejet engines. As a result of these works, designs of pulsejet engines were created, first valve and later sleeve-valve engines. The sleeve-valve pulsejet engine with 30 kg of thrust was used as an experimental drive for the "Boclan" glider for an independent takeoff. A subsonic ramjet engine with a thrust of 16 kg was used to drive the rotor blades of the "Trzmiel" experimental helicopter. Subsequently, the development of ramjet engines was oriented toward their use in subsonic and supersonic aircraft. A supersonic ramjet engine of 300 kg thrust was built. Later the scheme of works included the development of the combustion chamber of gas-turbine engines and afterburners and also solid-propellant rocket engines.

The scope of these complex studies included determination of the characteristics of ramjet and pulsejet engines; development of methods for thermal and gas-dynamic calculations of the combustion chambers of ramjet and gas-turbine engines and also afterburners; study of the processes of liquid-fuel combustion, simulation of stabilized and intermittent burning and stabilization of a flame under the unstabilized conditions of a flow and in a boundary layer; proposals of calculation and design methods for fuel injectors; studies of fixing in the combustion chambers, stability of the operation of subsonic diffusers and their characteristics, processes of solid rocket-propellants combustion, resonance and erosive combustion of solid propellants and proposal of methods for eliminating the reasons for their occurrence; and examination of questions of design, strength, and technology for manufacturing highly loaded elements of the combustion chambers.

The Department of Combustion consists of several subdepartments. The experimental base of the department consists of laboratories of gas dynamics, combustion, combustion chambers of gas-turbine engines, and a laboratory of solid-propellant rocket engines.

At the present time the department is involved in the study of combustion chambers of aviation gas-turbine engines, including those of helicopters; combustion chambers of solid-propellant rocket engines; power devices; and diesel engines.

Studies of vaporization-type combustion chambers of gas-turbine rocket engines have made it possible to:

- a) obtain high efficiency and dependable operation of the chamber over a wide range of excess air ratios;
- b) master the fuel vaporization processes in the vaporizing lines;
- c) master the flow of combustion processes in the primary section of the combustion chamber;

- d) select spark plug starting nozzle ignition systems;
- e) develop corresponding injector designs and technology.

At the present time, thorough studies are being carried out on regulating the temperature fields ahead of the engine turbine on ensuring a certain service life of a combustion chamber, on spark ignition of atomized liquid-fuel drops in a jet of air, and on the intermittent burning of a homogeneous gas mixture. As a result, the effect of the mixture parameters on the ignition energy has been studied, the ignition mechanism has been established, the theory of ignition has been developed, and the effect of accelerations on the rate of turbulent combustion and flame structure during turbulent combustion have been determined. In connection with this work, a method for visualizing the turbulent flame was established. In addition, studies were carried out on the stabilization of combustion of a two-phase mixture in a gas jet (air, nitrogen, and carbon dioxide). Kerosene, gasoline, diesel fuel, and propane were used as the fuel.

A large number of works encompass the studies of solid-propellant rocket engines designed for the "Meteor" meteorological rockets. Experience gained in the development of rocket boosters used for the acceleration of ramjet engines was used in the designing and study of these engines. The following were studied in these works: a) ignition of the solid propellant; b) its combustion in the temperature range from -54° to $+54^{\circ}$; c) erosive combustion; d) resonance combustion and elimination of its causes; e) the effect of accelerations on the combustion process during a flight; f) simulation of combustion.

Positive results of these studies have permitted the construction of two rocket versions: Meteor-1, with a flight altitude of 40 km with a payload of 0.5 kg, 1400 kg engine thrust and an average burning time of the charge of 2.3 s; and Meteor-2

with a flight altitude of 60 km, payload of 10 kg, engine thrust of 2400 kg, and 18 s burning of the charge. With two auxiliary booster engines the flight altitude of the latter is extended to 100 km.

Some of these works pertain to study on the use of combustion chambers and a magnetohydrodynamic generator channel, and also reactor injectors operating on liquid fuel.

Since 1966 the Institute has been working on high-speed diesel engines, which led to studies of the combustion processes in the chambers of these engines. In 1967 a five-year plan was developed for scientific research in the area of combustion, gas dynamics, and heat exchange in diesel engines. The five-year plan includes problems whose solution establishes bases for the modernization of diesels produced by Polish industry and for prospective studies concerning the increase of specific power by increasing the engine speed and the combustion of fuel with small excess air ratios. The problem has also been posed of adapting the combustion chambers to operate on various types of fuels.

The study of combustion, gas dynamics, and heat exchange in engines with self-ignition is necessary in order to establish the mechanism of combustion, knowledge of which is necessary for deliberate determination of methods for accelerating the processes in a diesel engine. The studies are carried out in the cylindrical combustion chamber of a single-cylinder engine with total visualization of the motion of the charge and the process of combustion. The studies are concerned with the motion of the charge, the fuel-injection process, and mixing; the conditions of self-ignition and combustion of the mixture and also the effect of the combustion process on the engine indicators are determined; chambers located in the piston and a chamber with direct fuel-injection are studied. The results of these tests will be used as informational material for the development of calculation methods using analog and digital computers.

The method for visualizing the processes, which was well recommended in the study of combustion in nonstabilized and stabilized flows, was used in the testing of diesel engines. The combustion chamber space of a four-cycle engine was observed through 6 quartz windows 2.2 mm in diameter. The observation results were recorded by means of a drum camera. The photographing of the process was done simultaneously with the measurement of the pressure in the cylinder. The turn angle of the crankshaft and time marks were recorded on the film. The method which was mastered on this engine for recording, on one film, the characteristics of the processes in the diesel chamber was used successfully for visualization of the combustion processes in a specially adapted single-cylinder two-cycle engine with a swirl combustion chamber. The swirl chamber was cylindrical with two quartz windows in the form of flat walls opposite one another. The processes of combustion were recorded by a high-speed motion-picture camera with simultaneous recording of the pressure in the cylinder and the angle of rotation of the crankshaft.

Visualization was also used to study the structure of vortex motion in a model swirl chamber made from plexiglass and to study the fuel atomization processes and mixing in the vortex flow in the "bomb" and a flat cylindrical chamber with quartz windows. Flow pictures were obtained by the schlieren method.

Another version for visualization of the process, based on the instantaneous illumination of the test object by a strong light source and its photographing, was used to measure the drop size. Attempts were made to photograph the drops while they were in motion. No satisfactory results were obtained due to the lack of a light source of sufficient intensity with short holding (less than 10^{-6} s). This system would permit one to photograph drops approximately 20 μ in diameter having a velocity of 1 m/s and drops with a diameter of less than 10 μ at a velocity of 0.1 m/s. The use of a laser should improve the results considerably.

A method was developed for photographing an atomized jet of fuel in the "bomb" while it is illuminated by a flash lamp at different phases of successive fuel injections. Using the atomization photographs, the range of the jet was determined as a function of counterpressure of the air compressed in the "bomb" with a constant pressure of fuel injection.

Furthermore, methods were developed for calculating the trajectories of fuel drops in the swirl chamber, for determining the amount of heat released in an engine as a result of the reaction based on the indicator diagram, and also for measuring the temperatures of the bottom of the piston and of the cylinder walls.

The results of some works which were mentioned were presented by the staff of the Aviation Institute at the II International Symposium on Questions of Combustion, which took place in October 1970 in the city of Jabtonna, Poland.